Eutrophication processes in Spanish reservoirs as revealed by biological records in profundal sediments

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Abstract

Eutrophication of reservoirs can be detected by changes in the abundance of insect and crustacean remains in the sediments. In recently constructed reservoirs, the time of impoundment can be determined through the presence of chironomid head capsules. The initial phase is characterised by highly enriched water as can be seen by the abundance of *Bosmina* remains. If further nutrient input into the reservoir remains low, the upper part of the sediment column is almost completely lacking in invertebrate remains.

Introduction

Paleolimnological studies in Spain have been few, and devoted only to paleo-lakes or estuarine bays (Margalef 1957, 1962, 1969). In other parts of the world studies of recent eutrophication revealed by changes in the biostratigraphic record, are common and a considerable amount of data exist (Carter 1977; Bengtsson & Persson 1978; Moss 1980). There are also more general accounts of the Quaternary history of lakes (Frey 1974, 1976). The association of different dating methods with historical records provides a good basis for studying the trophic status of lakes in the past, as exemplified by the fine study of the Bay of Quinte (Warwick 1980). But eutrophication processes in man-made reservoirs, although well documented in terms of contemporary plankton and benthos, have received little paleolimnological attention (Thomas & Soltero 1977).

As part of a study of more than 100 reservoirs in Spain (Margalef *et al.* 1976; Estrada 1975; Armengol 1980; Prat 1980), cores were taken in a number of these reservoirs and the results are presented in this paper.

Material and methods

Samples were taken with a simple gravity core of 1 m length, with a weight of 25 kg. Mud was retained in a plastic liner with an inside diameter of 2.4 cm, and a plastic valve underneath. The sampling method was not very effective and the maximum length of sediment collected was 50 cm.

Cores were frozen *in situ* with dry ice and preserved until examination, when they were cut at 2 cm intervals except for the core from the Yesa reservoir which was cut at 1, 2, and 4 cm intervals.

One gram of sediment was treated with 10% KOH according to Frey (1964) and filtered through two nets of 40 and 150 μm mesh. The material retained was diluted with water and examined with a stereoscopic microscope at 10 × and 100 ×. The mesh size was sufficient to retain chironomid and crustacean remains (Warwick 1980). Some diatom, dinoflagellate, and green algal remains were also found.

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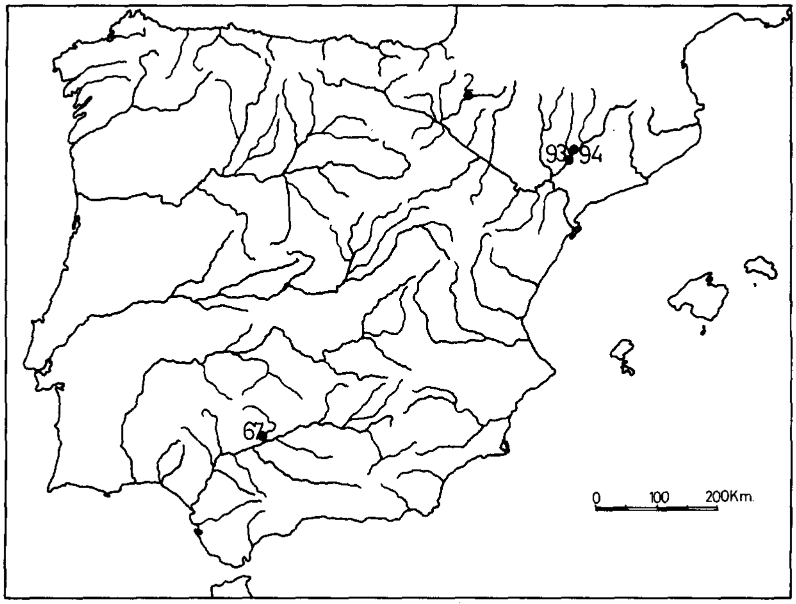

Fig. 1. Geographical situation of the four reservoirs sampled. 2 – Yesa, 67 – La Breña, 93 – Santa Anna, 94 – Camarasa.

Reservoir characteristics

Only a few cores contained more than 20 cm of sediment and a number of them were selected for detailed analysis by V. Daroca. The four reservoirs selected were Yesa (2), La Breña (67), Santa Anna (93), and Camarasa (94). The La Breña reservoir is the only one situated in the south of the Iberian peninsula (Fig. 1). The number in brackets is the identification code of the reservoirs as used in the general survey carried out on Spanish reservoirs (Margalef *et al.* 1976). The most important morphological and physicochemical features of the reservoirs, in addition to core data and profundal fauna taken with a grab sample are provided in Table 1.

Table 1. Geographical, morphometrical, chemical and core data for four Spanish reservoirs.

	Santa Anna	Yesa	La Breña	Camarasa
River	Noguera Ribagorzana	Aragón	Guadiato	Noguera Pallaresa
Impoundment year	1961	1960	1935	1920
Altitude (m)	375	490	121	333
Maximum depth (m)	80	60	52	91
Surface area (ha)	768	1900	600	624
Volume (10^6 m^3)	241	470	115	180
Flow (10^6 m^3/year)	946	1216	180	2181
Alkalinity (meq/l)	1'9	2'6	1'9	1'9
Phosphorous (μg-at PO_4-P l^{-1})	0'09	0'12	2'24	0'87
Chlorophyl (mg chl a m^{-2})	19	15	64	88
Core sampling date	30.4.1974	2.5.1974	14.3.1974	29.4.1974
Reservoir depth	54	48	23	60
Sediment in the core (cm)	18	32	28	30
Profundal fauna taken with grab	Tubificidae	Tubificidae *Procladius* Tanytarsinii	Tubificidae *Procladius* *Chironomus* *Microchironomus*	Tubificidae *Procladius*

The four reservoirs considered are large, deep, man-made lakes that differ in their morphology and flow conditions. Camarasa is deep and narrow but Yesa and La Breña are shallower and broader (Table 1).

All the reservoirs are alkaline, but not very eutrophic (Table 1) as can be seen from the phosphorous content of the waters and the mean chlorophyll *a* content per m^2. La Breña and Camarasa were included in the group of moderately eutrophic reservoirs (group V) and Yesa and Santa Anna were in the oligotrophic group (group VI) in the typological classification made by Margalef *et al.* (1976).

As can be seen from Table 1, tubificidae were frequent but chironomids scarce (Prat 1980). Larvae of *Chironomus* were collected only in La Breña. The most frequent Chironomidae were the larvae of the genus *Procladius*. However, *Procladius* was absent from our sediment data, perhaps because of the small size of the ligula that was not retained in the analysed samples.

Results

In Camarasa no remains of Chironomidae were found (Fig. 2). Only planktonic crustaceans and some Chydoridae were present in the core. Well-preserved remains of pennate diatoms and *Pediastrum* were also found. There are clear fluctuations in the number of individuals in the core but interpretation is difficult because the sediment accumu-

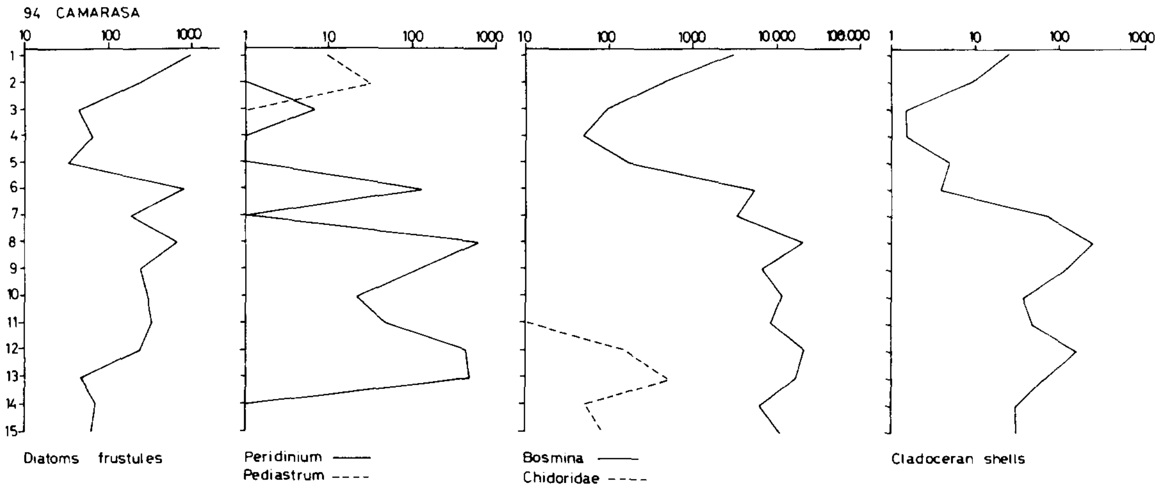

Fig. 2. Composition of fossil remains for a core from Camarasa reservoir. Number of individuals per 1 g dry sediment.

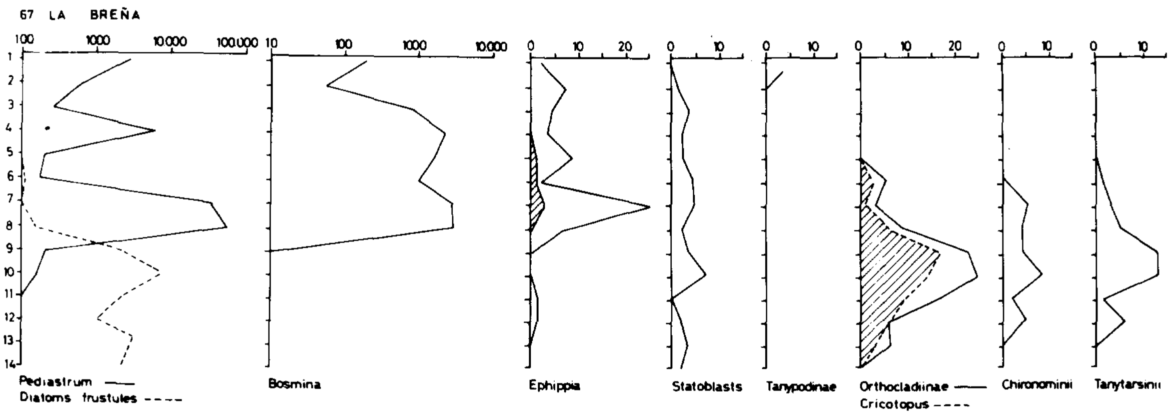

Fig. 3. Composition of fossil remains for a core from La Breña reservoir. Number of individuals per 1 g dry sediment.

lation rate is not known. It may be that differences in the retention time of the water in the reservoir is responsible for these differences. Rainy years with a rapid throughflow may correspond to lower accumulation of planktonic animals in the sediment.

In La Breña, (Fig. 3) the Chironomidae appear in the middle levels of the core and dominance by diatoms in the profundal layers is replaced by an increase in *Pediastrum* in the upper layers. *Bosmina* appears at level 8 and rises and remains high in the upper layers. Ephippia of *Daphnia* and Ceriodaphnia were also more abundant in the upper layers. In layers 9 to 11 the number and diversity of Chironomidae was very high. Using Hofmann (1971) we have found representatives of *Procladius, Cricotopus, Psectrocladius, Chironomus, Parachironomus, Dicrotendipes, Paratendipes, Stictochironomus, Paracladopelma*, and unidentified Tanytarsinii. But in the upper layers the rich chironomid fauna disappears.

In the more recently built reservoirs a clear difference exists between base and top of the core. In the upper layers (1 to 6) of Yesa reservoir, few remains of chironomids were found (Fig. 4). In the deepest layers (11–12) Chironominii were abundant (*Chironomus, Paracladopelma*, and *Polypedilum*) and Tanytarsinii were found more abundantly in the middle layers, between levels 6 to 9. At the base of the core Orthocladiinae were also abundant, especially *Psectrocladius, Cricotopus*, and *Parakiefferiella*. *Bosmina* appears at the base of the core, but its number is not as high as in the other reservoirs.

The most recent reservoir, Santa Anna, had a

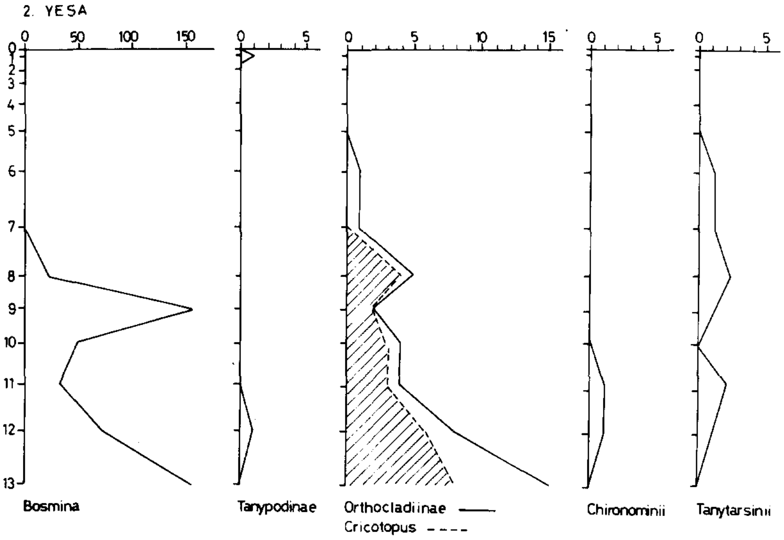

Fig. 4. Composition of fossil remains for a core from Yasa reservoir. Number of individuals per 1 g dry sediment.

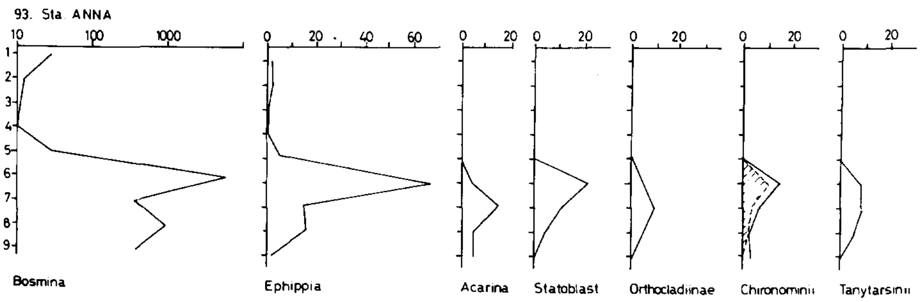

Fig. 5. Composition of fossil remains for a core from Santa Anna reservoir. Number of individuals per 1 g dry sediment.

clear lithostratigraphic change in the core taken in deep water. The lower sediment was dark and compact, similar to inundated soil; the more extensive upper zone was light brown, typical of mud from deep oligotrophic lakes. The upper layer had few fossil remains, while the lower one was very rich in such remains as *Bosmina, Daphnia* ephippia, statoblasts, and chironomids (*Chironomus, Polypedilum, Stictochironomus, Cryptochironomus, Cricotopus,* and *Psectrocladius*), and the concentration of organisms was especially high at layer 6 (Fig. 5), with abundant remains of *Chironomus* and *Bosmina* suggesting a eutrophication phase. The fauna disappears in the upper layers, and the reservoir was very oligotrophic at the time of sampling.

Discussion

The rate of sediment accumulation in reservoirs is very variable. Thomas & Soltero (1977) found a rate of 2–4 cm a^{-1} and 10 cm a^{-1} may be accumulating in some reservoirs. The rate can be very variable depending whether the reservoir is situated in a headstream, or located in a lower part of a series of man-made lakes. The rate will be higher in the upper basins. Camarasa and Santa Anna are the third basins in a reservoir series, while La Beña and Yesa are located in zones without other reservoirs upstream. In the absence of laminated sediments and radio-isotope dating, it is very difficult to assess the filling rate of the reservoirs. Undoubtedly 20 to 40 cm of sediment taken by our corer (Table 1) only provides data for the more recent events.

In Yesa and Santa Anna, recently completed dams, the base of the core could represent the time of reservoir impoundment. This may especially be the case in Santa Anna, where the mud structure and fossil remains are very different from the upper sediments. In Yesa, although the core went deeply into the mud it is unlikely that initial sediments were sampled since the reservoir is situated in a head water and probably has a higher accumulation rate than Santa Anna.

The variety of chironomid fauna when present, with especially *Psectrocladius, Cricotopus* and Chironominii other than *Chironomus*, suggests a rich development of the littoral fauna (Stahl 1969). The absence of littoral organisms can be due to morphometric and flow conditions of the reservoirs. Deep steep-sided reservoirs with a low water retention time (as Camarasa) restrict the development of littoral fauna and only planktonic elements were found in the sediments (Fig. 2).

In reservoirs with high retention times, and situated in broader valleys (as La Breña) fluctuations in water level may be greater, but when water level is low, and little water enters the reservoir, the temporary stability can allow a diverse littoral fauna, (with *Cricotopus, Psectrocladius, Glyptotendipes,* or *Paracladopelma*) to develop. Eutrophic conditions can occur at low water level situations and the replacement of diatoms by *Pediastrum* and the presence of *Chironomus* in the intermediate levels of the sediments in La Breña reservoir suggest this process. Later, the disappearance of chironomids and the dominance of *Pediastrum* and *Bosmina* remains, suggests a fluctuation in water level and eutrophic water.

As we have suggested the Santa Anna sedimentary record shows a complete history of reservoir development. The basal mud was very different in structure and some typical riverine insects (like *Euorthocladius*) were found. Many typical littoral chironomids were also found, suggesting a stable, low water level.

At level 6 of Santa Anna (Fig. 5), many *Bosmina* and *Chironomus* remains suggest an enrichment phase, in which the terrestrial vegetation decomposed and released nutrients to the water. After this phase, as the water entering the reservoir is nutrient poor, plankton and benthos declined, and *Bosmina*, for instance, became very scarce. Grab samples taken in Santa Anna demonstrated the absence of Chironomidae in the profundal zone and only some tubificids were found (Table 1). This oligotrophic phase explains the absence of fossil remains in the upper part of the core taken in Santa Anna (Fig. 5).

We can conclude that if reservoirs are built in a zone without incoming nutrients, after an initial eutrophic phase, reservoirs become oligotrophic leaving few fossil remains in the sediments. But water level fluctuations are very important for the trophic status of reservoirs. A period of low water level may result in reservoir eutrophication and the development of a rich littoral fauna. More investigation is needed to understand how the morphometric pattern, flow and water level fluctuations affect to trophic conditions of the reservoirs and the remains preserved in the sediments.

Acknowledgements

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